Decreasing Prescribing Errors During Pediatric Emergencies: A Randomized Simulation Trial

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abstract

OBJECTIVE: To evaluate whether a clinical aid providing precalculated medication doses decreases prescribing errors among residents during pediatric simulated cardiopulmonary arrest and anaphylaxis.

METHODS: A crossover randomized trial was conducted in a tertiary care hospital simulation center with residents rotating in the pediatric emergency department. The intervention was a reference book providing weight-based precalculated doses. The control group used a card providing milligram-per-kilogram doses. The primary outcome was the presence of a prescribing error, defined as a dose varying by ≥20% from the recommended dose or by incorrect route. Residents were involved in 2 sets of paired scenarios and were their own control group. Primary analysis was the difference in mean prescribing error proportions between both groups.

RESULTS: Forty residents prescribed 1507 medications or defibrillations during 160 scenarios. The numbers of prescribing errors per 100 bolus medications or defibrillations were 5.1 (39 out of 762) and 7.5 (56 out of 745) for the intervention and control, respectively, a difference of 2.4 (95% confidence interval [CI], −0.1 to 5.0). However, the intervention was highly associated with lower risk of 10-fold error for bolus medications (odds ratio 0.27; 95% CI, 0.10 to 0.70). For medications administered by infusion, prescribing errors occurred in 3 out of 76 (4%) scenarios in the intervention group and 13 out of 76 (22.4%) in the control group, a difference of 13% (95% CI, 3 to 23).

CONCLUSIONS: A clinical aid providing precalculated medication doses was not associated with a decrease in overall prescribing error rates but was highly associated with a lower risk of 10-fold error for bolus medications and for medications administered by continuous infusion.

WHAT'S KNOWN ON THIS SUBJECT: Medication errors are common in children. Characteristics of errors during critical situations in the emergency department are ill defined and might be more common than previously thought. However, optimal strategies to eliminate the risk of prescribing errors remain unknown.

WHAT THIS STUDY ADDS: We found that calculating medication doses in critically ill children introduces an unjustifiable risk of committing harmful prescribing errors. Precalculated doses for commonly used medications during emergency situations should be readily accessible for professionals caring for critically ill children.

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Dr Larose conceptualized and designed the study, designed the data collection instruments, coordinated and supervised data collection, was in charge of the simulation sessions, and drafted the initial manuscript; Dr Levy conceptualized and designed the study, designed the data collection instruments, coordinated and supervised data collection, and was in charge of the simulation sessions; Dr Bailey and Mr Lebel conceptualized and designed the study; Dr Cummins-McManus conceptualized and designed the study and was in charge of the simulation sessions; Dr Gravel conceptualized and designed the study, designed the data collection instruments, coordinated and supervised data collection, and carried out the initial analyses and statistical analysis; and all authors reviewed, revised, and approved the final manuscript as submitted.

This trial has been registered at www.clinicaltrials.gov (identifier NCT02563912).

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WHAT THIS STUDY ADDS: We found that calculating medication doses in critically ill children introduces an unjustifiable risk of committing harmful prescribing errors. Precalculated doses for commonly used medications during emergency situations should be readily accessible for professionals caring for critically ill children.
Medication errors are common in the pediatric population, and studies have reported errors in all settings. The emergency department (ED) is a high-risk setting for medication errors because of the high activity, the need to order medication urgently, a high-stress environment, and the possibility of missing patient information, including weight. Medication errors are particularly troublesome for critically ill children and those needing resuscitation. Characteristics of medication errors in cardiopulmonary arrest and code-related situations, in both the adult and the pediatric population, are ill defined but might be more common than previously thought. Observational studies have demonstrated a high rate of prescribing error during simulated pediatric resuscitation scenarios. Moreover, acutely ill children are often seen in community hospitals having little exposure and experience with pediatric patients. Alarming reports of deaths due to medication errors during urgent situations have been reported. Despite our knowledge and awareness, prescribing errors in pediatrics are still a common and reoccurring problem. Several strategies have been suggested to reduce medication errors but few have been studied, particularly those that occur in critical situations.

We aimed to evaluate whether the use of a clinical aid providing precalculated medication doses for children would decrease prescribing errors by residents during simulated cardiopulmonary arrest and anaphylaxis.

**METHODS**

**Study Design**

This was a crossover-randomized trial using high-fidelity simulation with residents rotating in the pediatric ED. Residents each performed 2 scenarios (with and without intervention) during the first session and served as their own controls during the second session (crossover session).

The study took place between September 2015 and January 2016 in a simulation center at a pediatric tertiary care academic facility.

**Participants**

All residents (PGY1 to PGY4) completing a rotation in pediatric emergency medicine during the study period were approached to participate in the study. Residents who previously participated in this study were not eligible to participate during a second rotation.

**Intervention**

The intervention of interest was the use of a book containing precalculated drug doses for commonly used emergency medications (Fig 1). The book was introduced to participants before the first session. The principal investigator briefly demonstrated its use to each group of residents in a standardized manner. Any question that came up was immediately addressed.

In the control situation, residents used a card containing the same list of medications but with doses indicated per kilogram, therefore requiring the resident to calculate the dose for a given weight (Fig 2). The card was presented in the same standardized way as the book (intervention). In the control situation, a preprinted order sheet requiring calculation was used for medications administered by continuous infusion (Fig 3). Residents were not allowed to use any other clinical aid but a calculator. The Broselow tape was available for weight estimation only.

**Outcomes**

The primary outcome was the presence of a medication error. An error was defined as a drug dose varying by >20% from the recommended dose or by incorrect route. Secondary outcomes included the time needed to prescribe the first medication. An unplanned secondary outcome included proportion of 10-fold error. Another outcome not related to simulation performances was resident confidence when using the 2 clinical aids.

**Questionnaire**

At the start of the study, each resident completed a questionnaire about their past experience in pediatric emergency medicine, level of training, and number of previous pediatric simulation sessions. Upon completion, participants were asked to rate their confidence level prescribing medications for children during emergency situations while using both cognitive aids provided to them (intervention [book with precalculated doses] and control [card]). This rating was done on a visual numeric analog scale from 0 to 10.

**Procedure**

**Simulation Sessions**

Participants completed 2 sets of scenarios in 2 different sessions 2 weeks apart. Scenarios were paired in such a way that they required the same tasks to be performed during the 2 distinct sessions (for anaphylaxis, ampicillin or peanuts; for cardiac arrest, ventricular fibrillation or pulseless ventricular tachycardia).

Scenarios were standardized and run in identical fashion by the same experienced simulation facilitators using Laerdal SimBaby and SimJunior, programmed identically. Residents acted as team leaders and were assisted by confederate nurses and respiratory technicians hired for the study. Nurse and respiratory technician confederates were previously trained to respond in the same way for each trainee.
The nurse confirmed all verbal orders given by residents but did not provide or suggest any correction. She did ask for clarifications if the order was incomplete (eg, route of administration not specified).

Scenarios were videotaped, coded, and stored. They were later reviewed and evaluated by 2 trained independent raters by using a standardized datasheet containing a list of recommended medication doses. Both raters were not involved in the study and were blinded to the study session and to the identity of the participant. In case of discrepancy between raters, the evaluation of the primary rater was used. Raters were experts in areas of pediatric resuscitation and experienced in simulation. Data collected included estimated weight according to the Broselow tape, time to order the first medication or intervention, doses and route of administration of any medication prescribed, fluid boluses, and shock (cardioversion or defibrillation).

### Randomization

For the first session, randomization was used to decide which type of case was the first (anaphylaxis or cardiac arrest) and which specific scenario was the first (eg, anaphylaxis to peanuts or anaphylaxis to ampicillin). Intervention and control were also randomized for the first session. For the second session, there was crossover of cases, scenarios, and interventions (Fig 4). Randomization was concealed until the beginning of the first case. Blinding of the participants or raters to the intervention was not possible because of the study design. However, participants were not aware of the study objective, and raters were blinded to the session phase (first versus second).
Statistics

Data were collected in Excel (Microsoft Corporation, Redmond, WA) and analyzed in SPSS version 21 (IBM SPSS Statistics, IBM Corporation). Because of the crossover design, where each participant was his or her own control, both groups (intervention and control) were well balanced for known and unknown predictors of success. The first analysis was intrarater agreement between raters via intraclass correlations (ICCs) for continuous outcomes and $\kappa$ statistics for categorical outcomes.

The primary analysis compared the number of errors per 100 prescriptions for bolus medications between both groups. Subsequently, the comparison of the proportion of scenarios without medication errors was conducted. A secondary analysis compared the proportion of scenarios with a 10-fold error between the 2 groups. Additional analyses compared the mean time for prescribing the first drug or the first defibrillation via linear regression and the association between risk of errors and risk factors via logistic regression. A 95% confidence interval (CI) was calculated for each measurement.

The sample size was estimated based on previous studies that suggested that 10% to 20% of prescriptions would have a medication error. Based on a consensus of experts in pediatric emergency medicine, it was estimated that an intervention decreasing the proportion of errors from 10% to 5% would be clinically significant. Thus, we estimated that an inclusion of 40 residents in a crossover design would yield a power of 80% to find such a difference with an $\alpha$ value of .05.

Ethics

Our institutional review board approved the study protocol. To be included, participants provided...
written informed consent. Participation in the study had no impact on the residents’ ED rotation or their evaluation.

RESULTS

Between September 2015 and December 2015, all 89 residents rotating in the ED were invited to participate in the study. Among them, 40 were eligible and agreed to participate. All residents completed

**FIGURE 3**
Preprinted order sheet for continuous epinephrine infusion (French only).

**FIGURE 4**
Study design for a given resident.
the questionnaires and participated in 4 scenarios. Most participants were junior trainees in family medicine and pediatrics (Table 1).

The 40 residents completed 4 simulated scenarios (total of 160 simulations). Interrater reliability between the 2 raters was good for most variables, with ICCs and $\kappa$ scores $>.70$ for all but 2 variables (Table 2).

Outcomes for intervention and control groups are outlined in Table 3. Mean and median numbers of medication orders were similar in both groups. The median number of medications prescribed was 8 for anaphylaxis scenarios and 11 for cardiac arrest scenarios. Ninety out of 160 (56%) scenarios were completed with no prescribing errors: 45 out of 80 (56%) in the intervention group and 45 out of 80 (56%) in the control group (Table 3). However, for bolus medications, 103 out of 160 (64%) scenarios were completed with no prescribing errors: 55 out of 80 (69%) in the intervention group and 48 out of 80 (60%) in the control group.

**Bolus Medications and Defibrillation**

A total 1507 medications or defibrillations were prescribed. There were 39 out of 762 (5.1%) medication errors for bolus medications in the intervention group and 56 out of 745 (7.5%) in the control group, a difference of 2.4 (95% CI, −0.1 to 5.0). Prescribing errors for medications or interventions most commonly involved epinephrine ($n = 31$), defibrillation ($n = 17$), and fluid bolus ($n = 7$). There were an equal number of errors for choice of defibrillation doses, 8 out of 20 (40%) in both groups (difference 0%; 95% CI, −18 to 18).

A total of thirty-three 10-fold errors occurred in 24 out of 160 scenarios: 7 out of 80 (8.8%) scenarios in the intervention group and 17 out of 80 (21.2%) in the control group, a difference of 12% (95% CI, 1.3% to 24%). According to logistic regression, use of the intervention was a predictor of a lower risk of a 10-fold prescribing error (odds ratio 0.27; 95% CI, 0.10 to 0.70). This finding remained statistically significant after adjustment for scenario type and study phase (first versus last session) and adjustment for participants (odds ratio 0.12; 95% CI, 0.03 to 0.47). Epinephrine was involved in 31 (93.9%) of the thirty-three 10-fold errors.

**Infusion Medication**

Residents ordered a continuous infusion medication during 152 out of 160 (95%) scenarios. Errors occurred in 3 out of 76 (4%) scenarios in the intervention group.
and 17 out of 76 (22.4%) in the control group, a difference of 13% (95% CI, 3% to 23%).

**Time to Prescription of Epinephrine or Ordering the First Shock**

There was no difference in mean times for ordering the first dose of epinephrine during anaphylaxis scenarios (125 seconds for intervention vs 124 seconds for control; 95% CI, −21 to 22) nor in mean times for ordering the first defibrillation during cardiac arrest scenarios (158 seconds for intervention vs 157 seconds for control [95% CI, −29 to 31]).

**Resident Confidence in Prescribing Medications When Using Clinical Aids**

Among the 40 participants, 39 (95%) reported being very confident (visual analog scale >7) when prescribing bolus medications by using the book compared with 29 (73%) for the control group (difference of 25%; 95% CI, 10% to 41%) (Supplemental Fig 5). A higher proportion of participants were also very confident with the book in comparison with the preordered sheet (control) for infusion medications (38 vs 18 residents; difference of 50%; 95% CI, 10% to 78%) (Supplemental Fig 6). Residents were not offered training. Additional training in using clinical aids could decrease medication error rates.

**DISCUSSION**

Medication errors are common in the pediatric population, and dosing errors are the most common type of medication errors. Children are particularly at risk for errors because doses must be adjusted to age and weight.

Results from this study showed that a clinical aid providing precalculated medication doses was not associated with a lower proportion of prescribing errors for bolus medications in general when compared with a tool providing milligrams-per-kilogram doses during simulated pediatric cardiac arrest and anaphylaxis. However, this clinical aid was highly associated with a lower proportion of 10-fold errors and a lower proportion of errors for medication administered by infusion. This is the first study evaluating usage of a dosage book providing weight-based precalculated doses during pediatric emergency situations.

A possible explanation for the absence of statistical differences in the proportion of errors for bolus medications between the 2 groups may be related to the proportion of error that was lower than anticipated in the control group. Previous studies have reported medication error varying between 10% and 26.5%, compared with 7.2% in our control group. This clinical aid was highly associated with a lower proportion of 10-fold errors and a lower proportion of errors for medication administered by infusion. The participants in our control group were provided with a card containing appropriate milligrams-per-kilogram doses, which is probably better than memory recall. We noted that although residents were instructed to use clinical aids, there were times when some residents relied on their memory, which could have contributed to errors in both groups. Residents were not offered training. Additional training in using clinical aids could decrease medication error rates.

Previous studies reported high proportions of medication errors in simulated case scenarios. An observational study demonstrated a potential error rate of 40.8% for the initial medications prescribed by residents. Some of the errors were corrected before drug delivery to the manikin, resulting in a final medication error rate of 26.5% (95% CI, 13.7% to 39.3%). Use of a cognitive aid did not statistically decrease the rate of medication errors. However, only 13 out of 49 (26.5%) participants used cognitive aids. In this study, the presence of

**TABLE 3 Study Outcomes**

<table>
<thead>
<tr>
<th>Study Outcomes</th>
<th>Intervention (n = 80)</th>
<th>Control (n = 80)</th>
<th>Difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median number of medications prescribed (first and third quartiles)</td>
<td>9 (11)</td>
<td>9 (11)</td>
<td>0</td>
</tr>
<tr>
<td>Mean number of medications prescribed</td>
<td>9.53</td>
<td>9.33</td>
<td>0.21 (−0.36 to 0.78)</td>
</tr>
<tr>
<td>Number of scenarios with no error for all medications</td>
<td>45 (58)</td>
<td>45 (58)</td>
<td>0.00 (−0.15 to 0.15)</td>
</tr>
<tr>
<td>Number of scenarios with errors in bolus medication</td>
<td>0.09 (−0.06 to 0.23)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of scenarios with errors in infusion medication</td>
<td>5.11 (39/62)</td>
<td>7.51 (56/745)</td>
<td>−2.40 (−4.91 to −0.77)</td>
</tr>
<tr>
<td>Number of scenarios with errors in defibrillation dose</td>
<td>1.13 (0.03 to 0.23)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of scenarios with errors in cardioversion instead of defibrillation</td>
<td>0.13 (0.03 to 0.23)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean time to first epinephrine prescription in seconds</td>
<td>125</td>
<td>124</td>
<td>1 (−21 to 22)</td>
</tr>
</tbody>
</table>
a clinical pharmacist significantly reduced medication errors. Although the presence of a pharmacist during emergency situations should be strongly encouraged, it is unrealistic to expect their presence at all times and during emergency situations across all settings. Also, pharmacists and other health care professionals are not immune to confirmation biases, selective attention, and oversights. In another study, 20 fellows and residents ordered 125 medications during 8 mock resuscitations. In 21 (17%) orders, the exact dose was not specified. Nine dosing errors occurred at the ordering phase, and of these, four 10-fold errors were identified. Route of administration was not specified in 49% of orders.

Standardization and preprinted order sheets are a low-cost intervention that has been shown to decrease the risk of errors. A study found that a standardized volume/weight-based system was associated with a reduction in medication errors compared with use of the Broselow tape during simulated Pediatric Advanced Life Support scenarios. A color-coded, prefilled syringe reduced critical dosing errors by emergency physician and nursing teams during simulated pediatric ED resuscitations. However, a recent simulation study found a high rate of error by paramedics administering epinephrine according to 2 different length/weight-based tapes (Broselow, 21.3% vs Handtevy, 16.3%). Pediatric epinephrine dosing in the prehospital setting is known to be error prone, even with standardization.

Computerized provider order entry (CPOE) with or without clinical decision support has been widely advocated for reducing prescribing errors. CPOE has significantly reduced errors in some settings while having no impact on others. Most studies have been conducted among hospitalized patients. Despite CPOE with clinical decision support, clinically significant prescription errors continue to occur in the pediatric ED. A recent study where residents participated in prescribing tasks by using a CPOE found that in urgent situations, participants were prone to make mistakes when using the numeric row on the main keyboard. One study describing the use of CPOE during resuscitation in the PICU found no prescription errors in the 2 years after implementation. Studies using CPOE are difficult to compare because electronic systems differ and the exact definition of errors varies.

The presence of 10-fold errors with epinephrine in our study and in previous studies is of great concern. The fact that epinephrine is provided in 2 different concentrations (0.1 mg/mL and 0.01 mg/mL) increases the risk of 10-fold errors. Moreover, the dose and route of administration of epinephrine change according to the underlying medical condition, which clearly adds to the confusion, thus increasing the risk of errors. A recent systematic review of the use of epinephrine in anaphylaxis found that providers often lack proper knowledge on administration and dosing of epinephrine. In addition, the labeling of products with ratios of 1:1000 and 1:10000 probably contributes to errors. The US Food and Drug Administration has recently requested changes in the labeling of epinephrine vials, prohibiting the use of ratios.

More residents reported being very confident (visual analog scale >7) in prescribing medication in emergency situations for children when using precalculated doses compared with using a card with per-kilogram doses. Increased confidence could be beneficial in providing more time for clinicians to focus on other important decisions and tasks when caring for acutely ill children.

Our study has limitations. It is unclear whether the proportions of medication errors found in our simulation study are generalizable to real patient settings during actual emergency situations. Simulation cannot fully reproduce the high-stress experience of real pediatric emergencies. However, because participants were observed, videotaped, and evaluated, a certain element of stress was present. In the context of pediatric resuscitations, where cases happen infrequently, simulation is a particularly useful modality and has been recognized as an effective pedagogical tool superior to traditional teaching methods.

Our participants were trainees with less experience than practicing physicians. However, with documented lower error proportions in residents and increased confidence, one could hope that a clinical aid providing precalculated weight-based dosages could prove even more useful for experienced practitioners in the ED.

The $\kappa$ value between reviewers for errors in perfusion medication was only .58. Error proportions could differ in the clinical setting.

CONCLUSIONS

In our study, a clinical aid providing precalculated medication doses was not associated with a decrease in prescribing errors in general but was highly associated with a lower risk of 10-fold errors for bolus medications and medications prescribed by continuous infusion. It was also associated with increased confidence by residents for prescribing medications for children. This intervention is easy to implement and is a low-cost way to reduce medication errors during emergency situations. We found that calculating drug doses in critically ill children introduces an unnecessary and unjustifiable risk of committing highly dangerous prescribing errors. Precalculated doses for commonly used medications for emergency
situations should be readily available in all settings where children could present in critical conditions. Nurses and physicians should become familiar with available tools. Additional measures including educational strategies must be undertaken to lower the rate of dangerous medication errors during emergency situations. It is likely that >1 strategy will be needed to counter medication errors in the ED,4,8,11,42

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ABBREVIATIONS
CI: confidence interval
CPOE: computerized provider order entry
ED: emergency department
ICC: intraclass correlation

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